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This is to certify that the attached English language document, identified as Color Synthesizing and Separating Optical System, is a true and accurate translation of the corresponding Japanese language document to the best of our knowledge and belief.

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COLOR SYNTHESIZING AND SEPARATING OPTICAL SYSTEM

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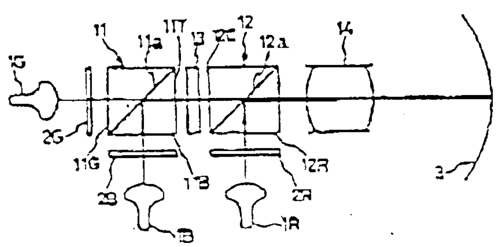
[54] **[Title]** Color Synthesizing and Separating Optical System

[57] **[Abstract]** (Corrected)

[Object] To provide a color synthesizing and separating optical system of small and compact configuration that is capable of preventing color change to the greatest extent possible.

[Configuration] The green wavelength component beam of a picture tube **1G** is polarized to P polarized light and the blue wavelength component beam of a picture tube **1B** is polarized to S polarized light. The respective polarized beams are made incident on a first polarization beam splitter **11** to synthesize the green and blue wavelength components, and the [synthesized beam] is made incident on a phase plate **13** to change the blue wavelength component beam from S polarized light to P polarized light. The red lightwave component beam of a picture tube **1R** that has been polarized into S polarized light is made incident on a second polarization beam splitter **12** to synthesize the red wavelength component with the primary synthesized beam comprising green and blue wavelength components, both of which have been polarized to P polarized light, thereby synthesizing a beam of the three primary colors RGB.



[Claims]

[Claim 1] A color synthesizing and separating optical system characterized by a configuration in which at least two polarized light separating members provided with polarized light separating films having an angle of 45° relative to the angle of incidence are positioned in the direction of an optical axis, and a phase plate having wavelength selectivity is inserted between said two polarized light separating members and aligned such that the direction of polarization of light of a prescribed wavelength component matches the direction of polarization of light of another wavelength component.

[Claim 2] In a synthesizing optical system for synthesizing the light of wavelength components of the three primary colors into naturally colored light, a color synthesizing and separating optical system characterized in that two polarization beam splitters having polarized light separating films with an angle of 45° relative to their respective optical paths are provided in the direction of an optical axis; a phase plate is inserted between said first and second polarization beam splitters; said first polarization beam splitter is formed with a polarized light separating film which passes light of a first wavelength component of the wavelength component beams of the three primary colors comprising linearly polarized light with a specific direction of polarization and reflects the light of a second wavelength component comprising linearly polarized light with a direction of polarization differing from that of said first linearly polarized light; said phase plate is configured to selectively change the direction of polarization of the light of said first wavelength component or said second wavelength component; and said second polarization beam splitter is formed with a polarized light separating film which either passes or reflects the adjusted light of said first or second wavelength component, and either passes or reflects the light of a third wavelength

component comprising linearly polarized light with a different direction of polarization than said passed or reflected light.

[Claim 3] In an optical system for separating linearly polarized visible light into wavelength component beams of the three primary colors, a color synthesizing and separating optical system characterized in that first and second polarization beam splitters having polarized light separating films with angles of 45° relative to their respective optical paths and first and second phase plates are provided in a configuration in which are arranged, in order from the side on which light enters: said first phase plate selectively changing the direction of polarization of the light of a first wavelength component among the light of the wavelength components of the three primary colors; said first polarization beam splitter separating from other wavelength components the light of said first wavelength component the direction of polarization of which has been thus changed; said second phase plate selectively changing the direction of polarization of the light of a second wavelength component among the other wavelength components separated by said first polarization beam splitter; and said second polarization beam splitter separating second and third wavelength components having different directions of polarization.

[Detailed Description of the Invention]

[0001]

[Industrial Field of the Invention] The present invention relates to color synthesizing and separating optical systems for color synthesis and separation in projectors displaying color images and photographic devices picking up color images.

[0002]

[Prior Art] For example, in three-plate solid photographic devices, the wavelength components of the three primary colors R (red), G (green), and B (blue) are separated from the object, the light of the individual RGB components is intercepted in three solid photographic elements that are provided and photoelectrically converted to obtain individual RGB picture signals. However, a dichroic prism is generally employed as the optical system employed for color separation of light from the object. Further, in projectors that create a color image by synthesizing the individual RGB color images and project it onto a screen, a dichroic prism is also used as the color synthesizing optical system to synthesize the three RGB images.

[0003] As is widely known, in dichroic prisms, dichroic films comprising multiple layers of interference filters are laminated on prescribed faces of the prism, and, for example, a dichroic film passing red wavelength component light and passing [sic] other wavelength component light, and a dichroic film passing green wavelength component light and reflecting other wavelength component light are formed on required prism faces of a bonded prism so that when visible light is made incident from a prescribed direction, it can be separated into the three colors of RGB. Conversely, when the three primary colors of RGB are made incident to the prism from prescribed directions, each of the wavelength component beams is sequentially synthesized and can be outputted as naturally colored light.

[0004]

[Problems to Be Solved by the Invention] The dichroic films in the above-described dichroic prism have angular dependence. Incident light that is vertical to the dichroic film is correctly reflected or passed, but when the angle of incidence changes, the reflection or passing

characteristics change. Thus, when a divergent beam or convergent beam is made incident to the dichroic film, since the passing ratio or reflection ratio partially changes due to the angle of incidence on the dichroic film, there are problems in that color balance is partially precluded, color reproducibility and color separation properties deteriorate, and image quality is compromised. In particular, since the dichroic prism is formed of a medium such as glass, the relation of the reflective index of the medium causes the angle of incidence on the dichroic film to become larger than the angle of incidence on the prism, which is troublesome in that it greatly compromises color reproducibility. Naturally, it is theoretically possible to reduce the angular dependence of the dichroic film, but eliminating angular dependence to a degree that yields the desired objective requires 100 or more layers of dichroic film. Thus, it is not practical to eliminate angular dependence.

[0005] For such reasons, the prior art employs nearly parallel incident light in color synthesizing and separating optical systems to prevent a decrease in color reproducibility. There are problems in that a somewhat large dichroic prism and lenses are required to achieve parallel beams of light with the [desired] angle of incidence, resulting in an overall increase in the size of the device configuration.

[0006] The present invention, in light of the above-stated problems of the prior art, has the objective of providing a color synthesizing and separating optical system of small and compact configuration that is capable of preventing color change to the greatest extent possible.

[0007]

[**Means of Solving the Problems**] To achieve the above-stated object, the present invention is characterized by a configuration in which at least two polarized light separating members

provided with polarized light separating films having an angle of 45° relative to the angle of incidence are positioned in the direction of an optical axis, and a phase plate having wavelength selectivity is inserted between the two polarized light separating members and aligned such that the direction of polarization of light of a prescribed wavelength component matches the direction of polarization of light of another wavelength component.

[0008] Further, in the case of a synthesizing optical system for synthesizing the light of wavelength components of the three primary colors, the present invention is characterized in that two polarization beam splitters having polarized light separating films with an angle of 45° relative to their respective optical paths are provided in the direction of an optical axis; a phase plate is inserted between the first and second polarization beam splitters; the first polarization beam splitter is formed with a polarized light separating film which passes light of a first wavelength component of the wavelength component beams of the three primary colors comprising linearly polarized light with a specific direction of polarization and reflects the light of a second wavelength component comprising linearly polarized light with a direction of polarization differing from that of the first linearly polarized light; the phase plate is configured to selectively change the direction of polarization of the light of the first wavelength component or the second wavelength component; and the second polarization beam splitter is formed with a polarized light separating film which either passes or reflects the adjusted light of the first or second wavelength component, and either passes or reflects the light of a third wavelength component comprising linearly polarized light with a different direction of polarization than the passed or reflected light.

[0009] Moreover, in the case of a configuration for color separation of the three primary colors RGB, the present invention is characterized in that the first and second polarization beam splitters having polarized light separating films with angles of 45° relative to the respective optical paths and first and second phase plates are provided in a configuration in which are arranged, in order from the side on which light enters: the first phase plate selectively changing the direction of polarization of the light of a first wavelength component among the light of the wavelength components of the three primary colors; the first polarization beam splitter separating from other wavelength components the light of the first wavelength component the direction of polarization of which has been thus changed; the second phase plate selectively changing the direction of polarization of the light of a second wavelength component among the other wavelength components separated by the first polarization beam splitter; and the second polarization beam splitter separating second and third wavelength components having different directions of polarization.

[0010]

[Operation] In the present invention, not dichroic films, but polarization beam splitters, for example, are employed in color synthesis and color separation as the polarized light separating members positioned in the polarized light separating film. As is widely known, polarization beam splitters are provided with polarized light separating films with an angle of 45° relative to the prism. Polarized light separating films have the properties of passing one linear polarized light component from among the two perpendicular linear polarized light components generally referred to as the P polarized light component and the S polarized light component in light incident to the films. For example, such a film passes the P polarized light component and

reflects the other linear polarized light component, for example, the S component. Thus, to synthesize the wavelength component beams of two colors, one of the wavelength component beams is polarized to P polarized light, the other wavelength component beam is polarized to P polarized light, and the beams are made incident to the polarization beam splitter from directions that are 90° from each other. The P polarized light components pass through the polarized light separating film and the S polarized light components are reflected by the polarized light separating film, synthesizing the two beams. Here, the beams of linear polarized light components must be made incident to the polarization beam splitter. Polarizing plates comprising, for example, liquid-crystal plates, can be employed to obtain linear polarized light such as P polarized light or S polarized light from a beam of randomly polarized light or the like.

[0011] To synthesize yet a third wavelength component beam into the output beam, another polarization beam splitter is aligned in the direction of the optical axis. However, since the output beams of the above-described first polarization beam splitter are in the form of a P polarized wavelength component beam and the other is in the form of an S polarized wavelength component beam, when the output beam of the first polarization beam splitter is made incident to the second polarization beam splitter as is, the polarized light separating film reseparates the two wavelength component beams. Thus, a phase plate is inserted between the first polarization beam splitter and the second polarization beam splitter. Here, the term "phase plate" refers to a 1/2 wavelength plate with wavelength selectivity which either S polarizes one of the above-described wavelength component beams or P polarizes the other wavelength component beam to match the direction of polarization of the two wavelength component beams. Thus, in the second polarization beam splitter, in the same manner as in the above-described first polarization beam

splitter, it is possible to synthesize incident beams comprising P polarized light and S polarized light from two directions, and thereby synthesize beams of, for example, the three primary colors of RGB.

[0012] Here, a P polarized light component and an S polarized light component are both present in the output beam of the second polarization beam splitter. To match the directions of polarization thereof, in the same manner as with the first phase plate, it suffices to configure a second phase plate with wavelength selectivity which is positioned on the output side of the second polarization beam splitter.

[0013] To separate into elementary beams of individual RGB wavelength components the wavelength components in the visible light range of natural light, in reverse to the above, the direction of polarization of one of the wavelength component beams from among the elemental beams is selectively changed with the second phase plate, after which the elementary beam whose direction of polarization has been changed with the second phase plate is separated from the other with the second polarization beam splitter. Then the direction of polarization of the wavelength component of one of the elementary beams is changed with the first phase plate and the two elementary beams are separated by the first polarization beam splitter, thereby permitting separation of the other beam containing the remaining two elementary beams into elementary beams comprised of individual RGB wavelength components.

[0014] Polarized light separating films have a lower rate of change in reflection and passing characteristics relative to angle of incidence than dichroic films. They also have an angular dependence that can be made so low as to be practically negligible even at 20 or fewer layers by changing the number of laminated layers of polarized light separating film, the composition of

individual layers, or their thickness. Thus, even when the angle of incidence is extremely high, as in the case of convergence and divergent beams, reflection and passing characteristics change little. The optical system itself can then be reduced in size, it is not necessary to provide a lens system to achieve parallel beams of light, and when employed in projection devices and photographic devices, a simple configuration yields extremely good color reproducibility and color separability.

[0015]

[Embodiments] Embodiments of the present invention are described in detail below based on drawings. First, Fig. 1 shows the schematic configuration of an embodiment in which an optical system for color synthesis has been incorporated into a projection device. In the figure, **1G** denotes a first picture tube outputting a green image, **1B** denotes a second picture tube outputting a blue image, and **1R** denotes a third picture tube outputting a red image. Further, to the output side of each of picture tubes **1G, 1B,** and **1R** are positioned liquid crystal plates **2G, 2B,** and **2R.** Numeral **3** denotes a screen. The images of each of the colors RGB from the first to third picture tubes **1G, 1B,** and **1R** are synthesized through beam synthesizing optical system **10** and a color image is projected onto screen **3.**

[0016] The color [sic] synthesizing optical system **10** comprises first and second polarization beam splitters **11** and **12** and a phase plate **13** positioned between polarization beam splitters **11** and **12.** In polarization beam splitters **11** and **12** are provided polarized light separating films **11a** and **12a** having respective angles of 45°.

[0017] The green wavelength component beam from first picture tube **1G** is polarized to P polarized light by liquid-crystal plate **2G** and enters entrance plane **11G** of first polarization

beam splitter **11**. The blue wavelength component beam from second picture tube **1B** is polarized to P polarized light by liquid-crystal plate **2B** and enters entrance plane **11B** of first polarization beam splitter **11**. The polarized light separating film **11a** of first polarization beam splitter **11** passes P polarized light and reflects S polarized light. Thus, light exiting from exit plane **11T** of first polarization beam splitter **11** is a synthesized beam of the green wavelength component and blue wavelength component.

[0018] Of the beams exiting first polarization beam splitter **11**, the green wavelength component is P polarized light and the blue wavelength component is S polarized light. Accordingly, a phase plate **13** is employed to match these differing directions of polarization. Phase plate **13** comprises a 1/2 wavelength plate with wavelength selectability. That is, phase plate **13**, as indicated by the solid line in Fig. 2, has the characteristics of changing the direction of polarization of light in the wavelength region of 400-500 nm from S polarized light to P polarized light and passing unchanged light in the green wavelength region, which is P polarized light. Thus, the output beam of phase plate **13** is a primary synthesized beam containing both a P-polarized green wavelength component and a P-polarized blue wavelength component.

[0019] Next, a color image is synthesized with the primary synthesis beam consisting of a green wavelength component beam and a blue wavelength component beam exiting phase plate **13** by synthesis of a beam of red wavelength component. A second polarization beam splitter **12** is provided for this reason. The above-described primary synthesis beam comprising P polarized light enters the entrance plane **12C** of second polarization beam splitter **12**. An S-polarized red wavelength component beam passing through a liquid-crystal plate **2R** from a third picture tube **1R** facing entry plane **12R** from a direction at 90° from entry plane **12C** also enters second

polarization beam splitter **12**. Of the two beams entering from two directions in this manner, the P-polarized primary synthesis beam passes through polarized light separating film **12a** and S-polarized red wavelength component beam reflects off of polarized light separating film **12a**, synthesizing an RGB three-color beam. The output beam from second polarization beam splitter **12** passes through a projection-use lens **14** and can be projected as a color image onto screen **3**.

[0020] Here, polarized light separating films **11a** and **12a**, as shown in Fig. 3, function to pass nearly 100 percent of P-polarized light and reflect nearly 100 percent of S-polarized light and are configured to highly suppress angular dependence. Polarized light separating films normally comprise multiple laminated layers of dielectric films such as TiO_2, ZnO_2, SiO_2, and MgF_2. These compositions, the number of laminated layers, and film thicknesses are suitably selected to obtain desired characteristics. For example, TiO_2 and MgF_2 can be employed as polarized light separating layers, and when the former is denoted as H and the latter is L, 11-layers of substrate $(45°)/(HL)^5H/$ junction/substrate suffice.

[0021] Phase plate **13** has the characteristics shown in Fig. 2. To achieve these, multiple layers of wavelength plate are employed. The optical axes of each of the layers of wavelength plate are set to a specific angle and the wavelength plates are adhered together. This changes the direction of polarization of a beam of a prescribed wavelength component and passes beams of other wavelength components with their directions of polarization unchanged, permitting control. For example, to rotate the direction of polarization of a beam in the blue wavelength region by 90°, three $\lambda/2$ wavelength plates with center wavelengths of 600 nm are employed. It suffices to arrange these plates with their optical axes at 28.5°, 55°, and 28.5° and make the angle of the direction of polarization of the angle of incidence 0°.

[0022] As set forth above, a configuration employing a polarization beam splitter in color synthesis controls changes in the passing rate and reflection rate by means of the angle of incidence. Thus, both convergent and divergent beams yield good color reproducibility in color images projected on screen 3. Since it is possible to significantly reduce the size of and render compact optical systems performing color synthesis and there is no longer a need to process images from individual picture tubes to obtain parallel beams, the overall configuration of projection devices can be reduced and simplified.

[0023] Next, a second embodiment of the present invention is shown in Fig. 4. The present embodiment shows the case where an optical system for three-color RGB separation is employed in a solid photographic device photographing an object.

[0024] In the figure, 21 denotes an image-forming lens, 22R, 22B, and 22G denotes solid photographic elements for photographing images of the individual colors of red, blue, and green, respectively. The image of the object photographed by image-forming lens 21 is separated into three colors by the color separating optical system and converted into electric signals by each of solid photographic elements 22R, 22B, and 22G. The color separating optical system comprises two polarization beam splitters 23 and 24 and two phase plates 25 and 26. Polarization beam splitters 23 and 24 are configured identically with the polarization beam splitters 11 and 12 of above-described Embodiment 1. The polarization beam splitter on the near side of image-forming lens 21 is first polarization beam splitter 23 and the polarization beam splitter on the far side from image-forming lens 21 is second polarization beam splitter 24. Phase plate 25 [sic: 26] positioned between polarization beam splitters 23 and 24 has precisely the same configuration as above-described phase plate 13 of Embodiment 1. This phase plate is second phase plate 26.

Further, the phase plate positioned on the image-forming lens **21** side of first polarization beam splitter **23** is first phase plate **25**. Between first phase plate **25** and image-forming lens **21** is inserted a liquid-crystal plate **27** as a polarizing plate to polarize light entering from image-forming lens **21** to P-polarized light.

[0025] First phase plate **25** changes to S-polarized light the 600-700 nm. or red wavelength component beam, of the wavelength components of light entering through image-forming lens **21** that have been polarized to P polarized light by liquid crystal plate **27**, and passes other wavelength components. A phase plate having the characteristics indicated by the dotted line in Fig. 2 is employed.

[0026] In a configuration such as that set forth above, the image of an object is picked up by a photographic device through an image-forming lens **21**, and the direction of polarization of the entering light is P-polarized by liquid-crystal plate 27. In first phase plate **25**, just the red wavelength component is selectively converted to S-polarized light and other wavelength components pass unchanged as P-polarized light through first phase plate **25**. When this beam then enters first polarization beam splitter **23**, the red wavelength component is separated from the others by polarized light separating film **23a** and directed into solid photographic element **22R**. Only the blue wavelength component of light passing through polarized light separating film **23a** of the first polarization beam splitter is polarized to S-polarized light by second phase plate **26** and the green wavelength component passes unchanged as P-polarized light. This beam is then divided into a blue wavelength component and a green wavelength component by polarized light separating film **24a** of second polarization beam splitter **24**, and directed into solid photographic elements **22B** and **22G**, respectively. These components are then

photoelectrically converted by solid photographic elements **22R, 22B,** and **22G**, producing individual RGB color image signals. In this manner, polarization beam splitters can be used to correctly separate light even when the incident light is divergent or convergent light.

[0027] In the color synthesizing optical system of above-described Embodiment 1, if a member identical to the second phase plate shown in Embodiment 2 is provided, the direction of polarization of the RGB output beams can all be identically aligned. Further, although P-polarized light was passed and S-polarized light reflected in the polarization beam splitters of both embodiments, a configuration in which this is reversed and S-polarized light is passed and P-polarized light reflected is also possible. Further, separation and synthesis are not limited to RGB. Not just three-color wavelength components, but the separation and synthesis of four or more differing wavelength components are also possible. In such cases, it suffices to increase the number of polarization beam splitters and phase plates.

[0028]

[Effect of the Invention] The present invention, configured as set forth above to be small and compact, has the effect of permitting good color reproducibility and extremely high precision color separation in the synthesizing of individual RGB color images, forming of color images, and separation of visible light into the three colors of RGB, regardless of whether the entering light is divergent or convergent.

[Brief Description of the Figures]

[Fig. 1] A block diagram descriptive of a projection device configured with the color synthesizing and separating optical system of the present invention.

[Fig. 2] The polarization characteristics diagram of a phase plate.

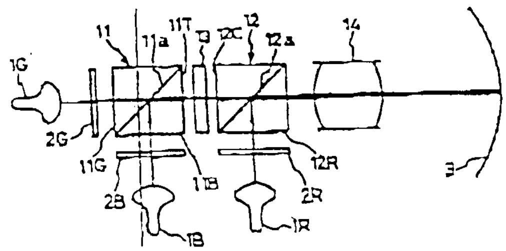
[Fig. 3] The characteristics diagram of a polarization beam splitter.

[Fig. 4] A block diagram descriptive of a solid photographic device configured with the color synthesizing and separating optical system of the present invention.

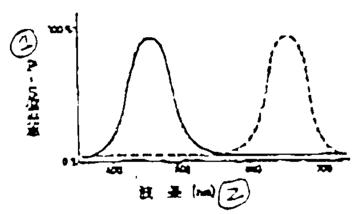
[Key to the Numerals]

1B, 1G, 1R	Picture tubes
2B, 2G, 2R, 27	Liquid-crystal plates
3	Screen
11, 12, 23, 24	Polarization beam splitter
13, 25, 26	Phase plate
21	Image-forming lens
22B, 22G, 22R	Solid photographic elements

[Fig. 1]

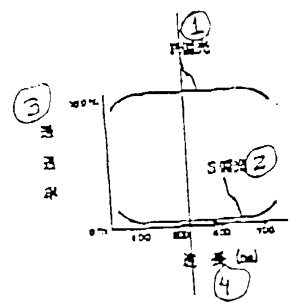


[Fig. 2]



[(1) P-S polarization rate (2) Wavelength (nm)]

[Fig. 3]



[(1) P-polarized light (2) S-polarized light (3) Passing rate (4) Wavelength (nm)]

[Fig. 4]